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UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

SPONTANEOUS COMBUSTION OF COAL

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O. P. HOOD

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SPONTANEOUS COMBUSTION OF COAL[1/]

By O. P. Hood[2/]

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GENERAL STATEMENT

The spontaneous combustion of coal lies at the bottom of the subject of storage. It is useless to store coal that is to be lost by fire from spontaneous combustion. Every engineer is familiar with the phenomena of the self-heating of coal, yet, for all that, spontaneous combustion is relatively rare. If we counted the times a portion of coal was stored where it would be undisturbed for a few weeks, the number of such storage operations in any one year would mount into the millions. Of these, a relatively small number show the phenomena of spontaneous combustion and the risk per ton is very small. It is extremely rare that in the smaller operations involving only a few tons there is any heating. There is no spontaneous combustion of anthracite, and very rarely does the domestic consumer of bituminous coal find troublesome heating. The main interest in the subject lies in the large piles needed as reserves for public-service utilities and the industries.

Everyone desires to have directions for storage that are perfectly simple and yet will insure against loss. Unfortunately, the problem is too complicated for a simple solution. Many of the factors involved are difficult to determine, as we have no practical means of quantitative measurement. The factors involve chemistry, physics, and engineering, and the man who is

1/ Reissued from Bureau of Mines Technical Paper 311: Factors in the Spontaneous Combustion of Coal, by O. P. Hood, 1922.
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in close contact with the problem of stored coal is not always a good observer in these several lines. The result is many incorrect theories, opinions, and prejudices. Much has been written on the subject, and the Bureau of Mines has published the results of extensive investigations, but the diversity of widely held opinions show that there is need of pointing out what are the factors that demonstrably are most concerned in the spontaneous heating of coal. This paper is an attempt to picture those factors so that a working theory may be held and observation centered on them.

I remember reviewing a case involving spontaneous combustion on shipboard, where in the hearings everything had been investigated, from the pennant on the mast to the barnacles on the rudder, but the observations that had a real bearing on the heating of the coal were extremely few and formed a very unpretentious part of a formidable-looking document. It is necessary to know what to look for in order to draw reasonably accurate conclusions.

SIZE OF COAL - FINENESS OF PIECES

The heating of coal is believed to be a surface phenomenon (fig. 1). If a ton of bituminous coal could be delivered in a single cube, each dimension of the cube would be about 2.8 feet. When coal heats, it is due to something that goes on with respect to the surface and not something that happens inside of the piece. So far as we know, this is true no matter how finely the piece is divided. We are, therefore, interested in the area of the total exposed surface in a ton of coal. If the cube, having originally an area of about 47 square feet, be continuously subdivided, the rate of increase in the exposed surface is as shown in figure 2. If the size of the pieces is reduced until all the pieces are fine enough just to pass through a 16-mesh screen the area of exposed surface becomes an acre. It is perfectly obvious from this why it is that trouble from spontaneous combustion originates in fine coal, because the great increase in extent of surface does not begin until we get below 1 1/4-inch, or nut size. If fine coal is kept out of the pile the heating surface is relatively so small as to remove the cause of spontaneous combustion. This remark applies not to the fact that one may buy lump coal but to the size of what actually gets into the storage pile. Coal bought as lump at the mine and handled with modern disregard for breakage may be far from lump coal when in the pile.

TEMPERATURE AT TIME OF STORAGE

A unit of area of this coal surface generates a certain amount of heat, provided the coal can find the combining material, that is, oxygen. The amount of heat generated depends upon the temperature of a piece of coal. That is to say, coal put into storage at a temperature of 80° F. will generate very much more heat per unit of surface than if put into storage at the temperature of 60° F. I can not say just how much more, but chemists tell us that in general the rate of chemical reactions doubles for every 10° rise in temperature, and if that applies in this case, beginning at a temperature 20° higher means a fourfold increase in the amount of heat generated. (Fig. 3.) It has already been a matter of observation that coal

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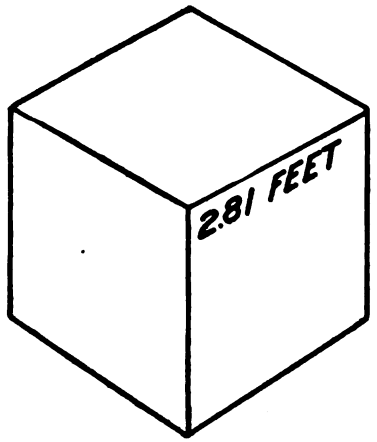

FIGURE 1.—One ton of coal in a solid cube. Surface area, 47.38 sq. ft.; volume, 22.19 cu. ft.

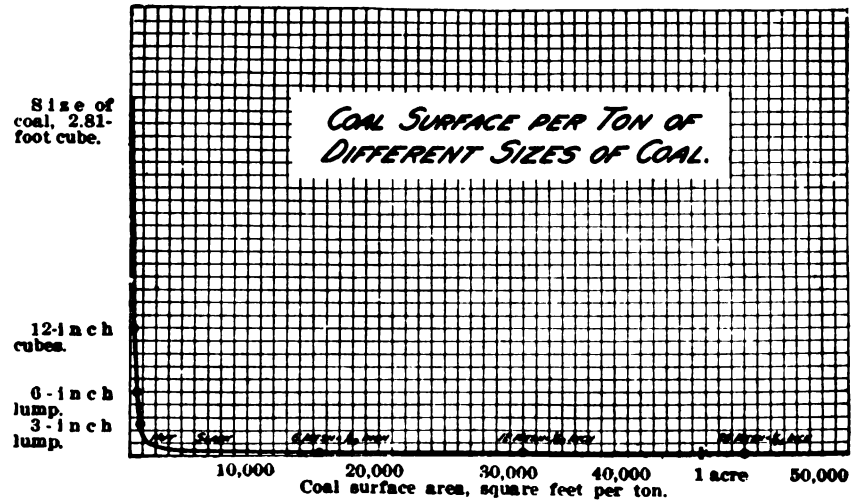

FIGURE 2.—Coal—surface area in square feet per ton of different sizes of coal.

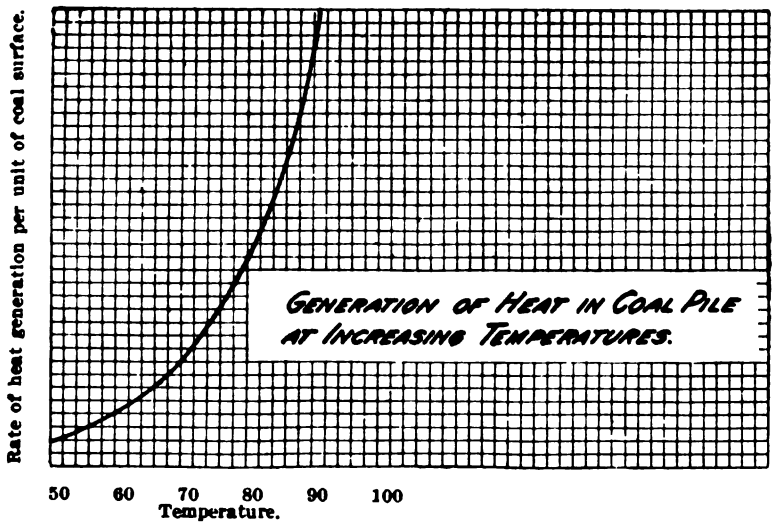

FIGURE 3.—Generation of heat in coal pile at increasing temperatures.

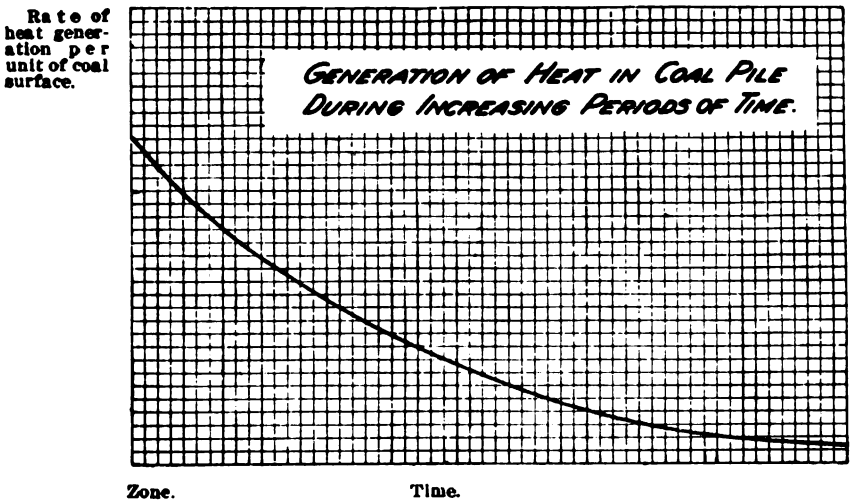
GENERATION OF HEAT IN COAL PILE DURING INCREASING PERIODS OF TIME.
Rate of heat generation per unit of coal surface.
Zone.
Time.

FIGURE 4.—Generation of heat in coal pile during increasing periods of time. Heat removed.

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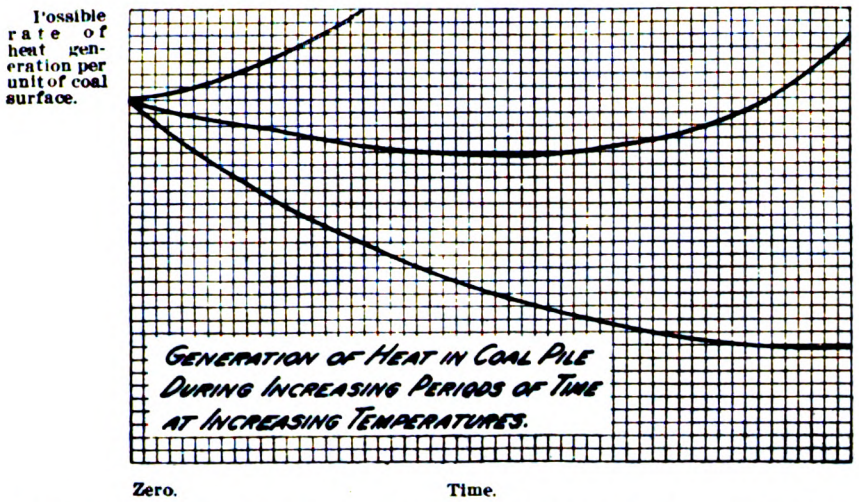
Possible rate of heat generation per unit of coal surface.
Generation of Heat in Coal Pile During Increasing Periods of Time at Increasing Temperatures.
Zero.
Time.

FIGURE 5.—Generation of heat in coal pile during increasing periods of time at increasing temperatures. Heat not removed.

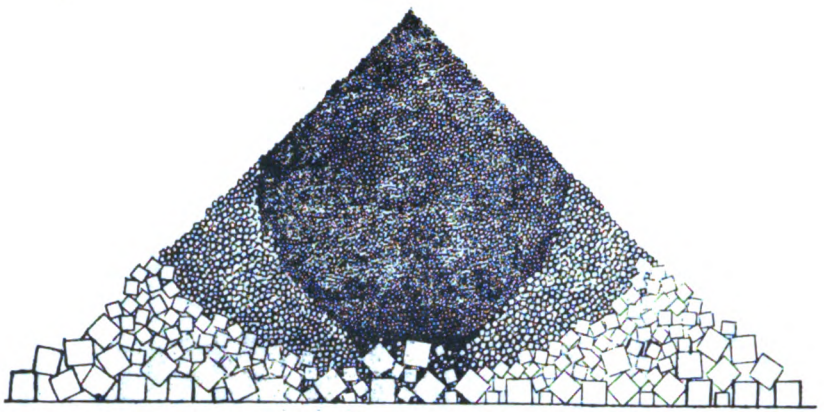

FIGURE 6.—Segregation of different sizes of coal in a conical pile.

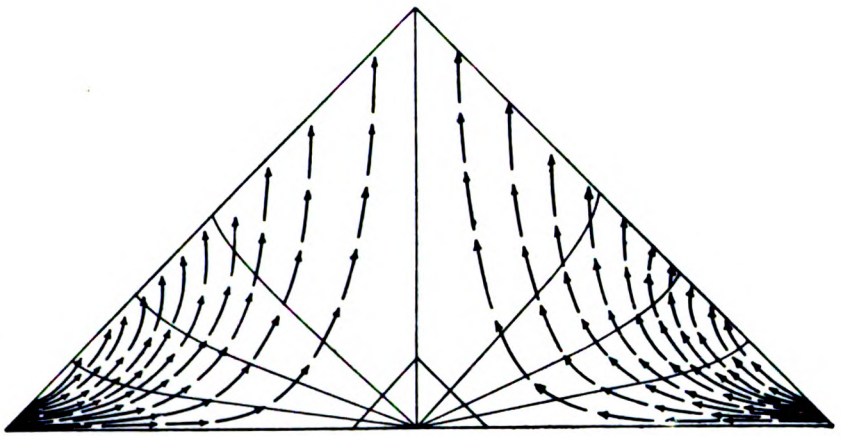

FIGURE 7.—Lines showing increasingly difficult paths for air circulation in a pile of coal.

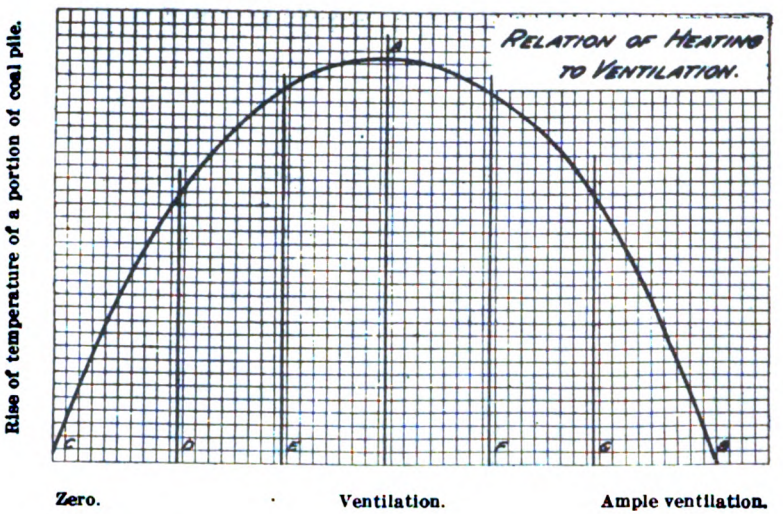

FIGURE 8.—Relation of heating to ventilation in a pile of coal.

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stored during the hot months of summer and in heated regions is much more liable to spontaneous combustion than coal stored in colder climes and in cooler seasons of the year.

FRESHNESS OF COAL SURFACES

Another most important factor is the freshness of the broken surface. A freshly broken surface of coal has a rate of heat generation that is a function of the kind of coal. It is practically zero with anthracite and is largest with the younger coals. The quantity of oxygen contained in the coal seems to be the fairest measure of this rate, although it is by no means reliable. The high-oxygen coals of the Middle West and the subbituminous coals and lignites of the West show increasingly active rates of heating.

In time, the coal surface apparently becomes satisfied, that is, nearly ceases to take up oxygen, and the heat produced falls practically to zero. The rate of heating then follows a curve somewhat like that given in figure 4. This means that for the first few days or weeks a freshly broken surface is very much more active than after a few weeks or months - a fact that must be borne in mind when considering the wisdom of crushing coal immediately before storing it. Spontaneous fires rarely occur after the coal surfaces have been exposed for three months.

RISE OF TEMPERATURE TO DANGER POINT

As the rate of heating increases with the temperature, it is evident that if the heat generated is not removed, the process becomes a self-aggravating one, and the rate of heat generation instead of falling as in figure 4, may rise with time according to some such curve as is shown in figure 5. If the temperature of the pile reaches 140° or 150° F. and continues to rise, there is a high probability that within a few days or a few weeks a destructive temperature will be reached. If the temperature reaches 160° or 180° F., there is almost a certainty that a destructive temperature will be reached and that the coal must be moved. Immediately the question of getting rid of the heat is presented.

DISSIPATION OF HEAT GENERATED

A coal pile is cooled by radiation and by the movement of air through it. Air moves rather freely through a pile of coal. To illustrate this point, one may cite a partial cargo of coal that was loaded into a bottom at New York and carried under sail to Norfolk. The general temperature of the pile at loading was known; on arrival at Norfolk the temperature of the coal had so increased as to make the adding of further cargo dangerous. From the known rise in temperature of the coal, it was possible to figure roughly the exchange of air that must have been made within the partial cargo in order to supply the amount of oxygen represented by the heating effect. The general order of magnitude was that all of the air in the interstices between the pieces of coal must have been changed 20 to 30 times during the time of heating. This coal was, of course, protected from winds, and the illustration shows how great may be the natural ventilation produced within

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a coal pile by differences in temperature and by the daily variations of barometric pressure. In many piles of coal this natural change, or breathing, of air is enough to carry away the heat generated.

SEGREGATION OF COAL BY SIZES IN A PILE

Suppose that coal is delivered in four uniform sizes and put in a conical pile by dropping at a single point. (Fig. 6.) The granular arrangement of parts will be such as to furnish a foundation, under nearly the whole pile, of larger sized pieces and the lower flanks of the pile will also be of the larger sizes. Nearly all of the smallest pieces will be in the central core of the pile. If one were to draw lines bounding the region of these several sizes they would be something like those shown in Figure 7.

ACCESS OF OXYGEN - VENTILATION

In the region of large pieces in such a pile the air would move freely and the area of coal surface exposed would be a minimum; hence there would be little likelihood of heating. In the center of the pile the movement of air would be small and the total of heating surface would be great. If the fine coal is so densely packed as to prevent an exchange of air, there will be no heating because there will be no supply of oxygen to combine with the active surfaces. Somewhere between the two extremes of the central core of fine coal and the large-piece region there may be areas where the ventilating current is just sufficient to supply oxygen for a maximum rise in temperature and insufficient to remove the heat as generated. In figure 7, lines have been drawn showing in general the progressively difficult paths for the movement of cooling air.

Some observers have stated that, in general, fires in large coal piles are found in the region from 5 to 8 feet below the surface on the flanks of the pile. The rise in temperature of a coal pile is thus intimately connected with a very complicated ventilating problem, and we have no means of observing or measuring these small and wayward ventilating currents.

We know that if coal can be sealed tight, as in a glass jar, the oxygen soon disappears and the coal can not continue to heat because of lack of oxygen. In figure 8 the Horizontal distances represent the amount of ventilation of any portion of a coal pile and the vertical distances represent the rise in temperature. With no ventilation there will be no rise in temperature and the zero point will represent the condition of coal sealed from the air or so densely packed that air can not circulate. If, on the other hand, there is enough ventilation, the heat is all carried away as fast as generated and some point, as at B on the zero line, must represent this condition, as in the case of coarse coal. At some point, as at A, between these two extremes there may be a condition of ventilation which will supply just oxygen enough to provide for a maximum rise in temperature. What sort of a curve represents all of the intermediate conditions between C, A, and B we do not know, but that the curve must first ascend and then descend is perfectly evident. This curve teaches that if we have a condition of ventilation as at D, an increase in the ventilation to E will produce a more favorable condition for a

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temperature rise. On the other hand, if the original condition is as at F, and we increase the ventilation to G, we can expect a reduction of temperature. Since we have no means of knowing just what the ventilation is in any given portion of a pile, there is great hesitancy in advocating ventilating schemes for coal piles, as we are as likely to make trouble as to prevent it, unless extreme and uniform ventilation is assured.

These curves illustrate the tendencies of what are believed to be the principal factors in the problem of spontaneous combustion.

There are many more factors of minor importance. One of the troubles has been that undue attention has often been given to the minor factors, such as the sulphur or the volatile-matter content of the coal, height of pile, etc., while the main factors, such as initial temperature, breakage in handling, freshness of the coal, and the screening before storage, have been overlooked or minimized.

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